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ACCOMMODATING ANTENNA SYSTEMS
IN THE
SHIP DESIGN PROCESS

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- ABSTRACT -

Placement of the many and varied antenna systems required for a multitude of missions is a complex task in the ship design process. The competition for useable real estate on which to locate antennas, striving, for example, to provide good vertical height to attain clear radiation/reception, and sufficient horizontal separation to maintain transmit-to-receive isolation is acute, where great amounts of C^3 (command, control, and communication), Navaids, ECM, radar, and gun-fire control functions must be satisfied while immersed in a small, concentrated, and hostile electromagnetic environment. — C3

This presentation discusses the iterative processes involved in accommodating topside antenna systems aboard Navy ships where an especially large number of electromagnetic sensors is clustered on and about the masts and superstructure. The long road from initial concept is outlined, to the final antenna configuration compromise reached in an arena of fiercely competing subsystems. In providing this description, opportunities might then be identified for improving the support available from the technical community.

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Initiating the Ship Design Process - General Philosophy

How does an antenna become designated for service, and ultimately installed, aboard a Navy surface ship? Whether for use in navigation, or weapon fire control, or communications, or electronic countermeasures, or for any other reason, the answer should be, simply: it's part of the ship design process. Though the answer is simple, the process is not. Topside design, in particular, is a long, arduous, frustrating series of compromises among system designers competing for platform space and arrangements. The invariable result is degraded performance, degraded to some minimally accepted degree of service to fulfill a specified need.

But, just how does the ship design process begin? One overview of the origination and process is well described in a NAVSEA booklet entitled Ship Acquisition - REEF POINTS,(1) with excerpts germane to this discussion paraphrased as follows:

The responsibility to be capable of accomplishing certain defined missions imposes in turn the responsibility to define and develop shipboard systems to meet identified needs. Establishing requirements for a topside system usually begins with the identification of a need for a specific capability within a mission, and proceeds through such steps as establishing some relative priority of need, defining performance characteristics, assessing the technical risk and, finally, selecting a system that promises to provide the required capability.

The plans developed by the Navy and the other services to carry out this responsibility are coordinated by the Secretary of Defense by way of the Joint Chiefs of Staff (JCS). The Secretary of Defense provides the broad national defense policies and objectives. The JCS translate these into military policies and objectives, based on assumptions of the capabilities and intentions of potential enemies. This constitutes the framework for planning and programming at the service level.

The initial design process begins at Chief of Naval Operations (CNO) level with consideration of national objectives and policies, and available technology. Next, studies of trade-offs among missions and tactics, technology, and available resources are conducted, in which the needed operational and technical capabilities are identified. Regardless of the source of the need being identified, the official recognition of the requirement occurs with the preparation and submission of a requirements document - the Operational Requirement (OR) or Required Operational Capability (ROC).

The OR

When the Chief of Naval Operations has defined the mission and requirements for a particular type ship, an Operational Requirement is issued, which is the basic document for all Navy acquisition programs. Thereupon the Chairman, Ship Acquisition and Improvement Panel (SAIP), OP-03, is directed to initiate ship program studies and to begin the iterative process for establishment of the Concept Baseline documents.

A Program Coordination Group is established composed of the program coordinator and representatives from OP-96 (Program Planning Office), OP-98 (Office of R&D), the Chief of Naval Material, and other organizations as may be required, to develop the initial draft of the Top Level Requirements (TLR) document during design definition. This "kick-off" of the design process is depicted in the functional flow diagram of Figure 1, as Block 1.

The TLR (Block 1 of Figure 1)

The Top Level Requirements is a document, promulgated and approved by CNO, which defines the operational requirements of the ship to be produced, and stipulates maximum cost, and all other program constraints affecting the design and utilization of the ship, based on the initial cost and feasibility studies. As a minimum the TLR states the ship's mission, operational requirements, major configuration constraints, maintenance and supply support concepts, manning limitations, and minimum operational standards. It defines what the user (OPNAV) expects from the product as obtained from the producer (NAVMAT).

Through continuous iterative dialogue between OPNAV, NAVMAT, and NAVSEA, a clear understanding of the requirements is gained, with assurance that the requirements can be met and ship produced within the state-of-the-art technology using resources which will be available within the time frame envisioned. The system proposed in the TLR is then better defined in terms of specific performance characteristics, schedule, and cost. In addition, alternative hardware systems, tactics, and technologies are considered to ensure that the most effective, efficient, and economical system is acquired to fulfill the need. In parallel with this refinement of the TLR, the development of the draft Top Level Specifications (TLS) is begun by NAVSEA.

The TLS (Block 2 of Figure 1)

The Top Level Specifications translate the TLR into a description of the ship, providing a bridge between the TLR and the contract specifications that will be developed for the procurement of the ship. It states what the producer, NAVSEA, intends to provide as the solution to the requirements of the user, OPNAV. Through the iterative dialogue, the ship and the ship systems are narrowed down, based on feasibility studies, into a preliminary concept. Alternative concepts involve mixes of performance parameters as well as shipboard systems, i.e.. candidate systems and options.

The ship design framework is now well established. The engineering process begins.

Design Phases

There are basically two distinct phases of design:[2] functional and detail. Functional design encompasses the Navy breakdown of concept, preliminary, and contract designs. This phase involves the translation

of top level system requirements into performance and other design requirements for each functional element of the ship system. A ship envelope is established; space allocations and a general arrangement are defined; tradeoff studies are performed, and system configurations selected; required equipments are identified; and all functional and some physical interfaces are defined.

In the later stages of the functional design phase, when critical elements of the design begin to be firmed up and long lead time equipment is procured, it becomes necessary to exercise <u>configuration control</u>. Configuration control is a process by which changes in one area which affect another cannot be made without management approval. Such control must be judiciously applied because of its potential for encumbering the orderly progress of the design activity.

Given a defined configuration of every functional element such that the top level ship system requirements are satisfied, the detail design phase then defines the exact physical location and manner of physical installations of the ship's hardware. The details of how each component is to be mounted and installed are developed. The output of detail design instructs the shipbuilder how to construct the ship.

<u>Generating Topside Antenna Systems - General Philosophy</u>

With the exception of communications antennas, the designating of specific antennas to fulfill specific functions is fairly straightforward. That is to say, the documents issued from CNO (e.g., the TLR or the OPNAV Approved Ship Characteristics) will state explicitly each antenna, by nomenclature, to be used for surface search radar, air search radar, navigation, target illumination/tracking, ECM, IFF, etc. The reason that these are spelled out straightforwardly is that the choice is simply the latest generation antenna available. If not available in the inventory, the next best available prior-generation is selected. If some future generation antenna is in the R&D cycle, as is frequently the case, then space and weight is allocated in the shipboard material listing, and the topside design analysis. Thus, by CNO direction, in coordination and consultation with NAVSEA and NAVELEX, these antennas are selected and designated for use on specific ships very early in the design process.

Such is not the case for communications antennas. The selection of these antennas, always done by NAVELEX, for use with the many transmitters and receivers, at many frequencies from LF through SHF, is complex. As is the case with all portions of the ship design process, it originates at CNO level, (Block 1 of Figure 1), with a document entitled OPNAVINST C2300.44 - Communications Characteristics for U.S. Navy Ships,[3] using policies and procedures from CNO publications NWIP 11-20D - Missions and Charcteristics of U.S. Navy Ships and Aircraft,[4] and NWP 16E - Basic Operational Communications Doctrine.[5]

NWIP 11-20D

This publication "provides guidance to the naval operational planner in the employment of various types of ships. Missions, primary and secondary mission areas, and characteristics of Navy ships are set forth."(5)

Each individual type of U.S. naval vessel is categorized therein, accompanied by a General Mission statement, with Primary and Secondary mission areas. An example might go something like this (the specific missions of specific ships is classified information; to avoid classification a ficticious ship and missions will be illustrated):

General Mission:

. To operate as a part of surface strike forces, contributing to air, surface, and submarine defenses of these forces; to seek out, engage and destroy enemy surface forces; to attack targets along hostile shores; to provide command and control services to support fleet commanders; and to operate in support of amphibious operations.

. Mobility: MOB 1, 4, 5, 9, 19

. Command and Control: CAC 2, 3, 7, 11

. Anti-Air Warfare: AAW 2, 3, 4, 6, 11, 15

. Anti-Submarine Warfare: ASW 1, 4, 20

. Surface Warfare: SUW 1, 2, 3, 7, 12

. Secondary Mission Areas: Special Warfare: SPW 1, 4, 9
Fleet Support Operations: FSO 2, 3
Non-Combat Operations: NCO 3, 4, 10

Knowing these specified missions, the OPNAV communications planners are then able to determine the communications requirements necessary in support of the missions.

NWP-16E

"This publication contains basic operational communication doctrine and procedures for the guidance of the operating forces of the U.S. Navy and Marine Corps."(6) Pertinent statements are extracted as follows:

. The control and use of communications is a function of command. CNO, under the Secretary of the Navy, exercises overall authority throughout the Department of the Navy over communications. OP-094 is the Director of Command, Control and Communications (C^3) Programs exercising overall authority throughout the Department of the Navy in matters pertaining to communications and the radio frequency spectrum, and to determine, renew, validate, and approve requirements for the Department of the Navy.

. Naval communications are the means by which a commander makes his will known and, as such, are the voice of command. Modern warfare requires communications systems ranging from advanced radio networks to those with simple visual devices. Shipboard radio frequency compatibility (electromagnetic compatibility) problems become more serious in direct proportion to the number of electronic systems simultaneously in use, their outputs, transmission rates, and receiver sensitivities. Harmful material interference can be caused by unwanted emissions or intermodulation products. This takes the form of spurious, locally generated emissions (or their by-products) which may block and distort a portion of the signal at the receiver. Communications personnel can reduce self-generated interference and its effects by strict adherence to operating procedures and maintenance programs. It is essential that frequency separation criteria be determined for each ship and then observed in the development and use of frequency plans.

With this background of individual ship missions, and Navy communications policies and procedures, the principal document for determining specific communications requirements, OPNAVINST C2300.44, Communication Characteristics for U.S. Navy Ships[3] will be examined next.

OPNAVINST C2300.44

Purpose: To promulgate a consolidation of CNO approved communications characteristics for U.S. Navy ships, aircraft, and designated craft to support the missions as specified in NWP 11-20.

. Provides the approved communications characteristics by ship type. Unless specific classes within a type are listed separately, the requirements apply to all ships of the type.

. The number and type of antennas, multicouplers, and tuners vary with the type and quantity of transmitters and receivers installed. The requirement for an appropriate antenna system is implied by the RF requirement shown.

A detailed description is given of each type of communication system, and the quantity of transmitting, receiving, terminal systems, infrared, and special facilities is specified for every ship type. It is to be noted that only the communications systems requirements are provided, not the type of equipment. It is this document, C2300.44, from which NAVELEX must determine the equipment, including the antennas, necessary to satisfy the specified requirements.

NAVELEX Communications Systems Design

The total responsibility for the design and interoperability of ship communications systems resides in NAVELEX.[6] This includes preparation of communication antenna arrangement and location plans based on model range evaluations. As such, NAVELEX is a Participating Manager in Ship Acquisition, tasked and funded by the SHAPM either by the SPD (Ship Project Directive) or separate WTA (Work Task Assignment).

To initiate the communications system design process, NAVELEX must first review in detail the aforementioned CNO documents (references 3, 4 and 5) stating the ship's missions and tasks, and the communications systems required to support each mission area.[7] From these a circuit analysis is performed, (Block 2 of Figure 1) categorizing each circuit step-by-step as to usage, transmit/receive, frequency range, simplex/duplex, emission mode, etc. Additionally, the percentage of use is projected to ascertain which circuits will require allocated equipment and which might share equipments.

As an example of the NAVELEX process, portions of an actual study, that of the strike cruiser (CSGN), will be cited as follows:[8]

. The objective is to develop and describe the external communications characteristics for the CSGN Class ship as derived primarily from the "Combat System Tactical Operational Requirements for CSGN Class ships (U), Chief of Naval Operations, 20 December 1974."

. The procedures used in the development of these requirements is: Phase I was the determination of the operational capabilities defined by CNO requiring external communication support. Phase II represents the development of the specific circuit requirements to fulfill the operational need lines established in Phase I. Phase III correlated the CSGN circuit requirements of Phase II with specific functional characteristics in order to develop an External Communications Functional Plan.

. The CNO listed missions were examined line-by-line to determine those areas (i.e., MOB, CAC, AAW, ASW, SUW, SPW, NCO) requiring external communications support in transferring information to/from another facility in order to accomplish the designated functional task.

. Tables were compiled in matrix form summarizing the complete characteristics of each recommended circuit (type, emission, frequency, use, mode, effective range, availability, survivability, bandwidth, error rate, frequency separation, security requirements, etc.).

Having established the circuits necessary to meet the overall communications requirements, it is then the responsibility of NAVELEX to follow up with equipment selection and availability to satisfy the circuit requirements.

Background Summary

The general foundation and background for initiating the ship design process has been laid, beginning with the CNO directed mission criteria, through the converting of these into performance and technical requirements, up to the selection of electronic equipment and systems to meet the needs. We are ready at this point to discuss in detail the process of topside antenna system design and integration.

Topside Antenna Systems Design and Integration - Detailed Process

The Naval Ship Engineering Center, (NAVSEC), Code 6174F, is responsible for the design, integration, and configuration control of the ship's total topside antenna systems. Tasking and funding is provided in the form of a Work Task Assignment (WTA), which includes a description of the work to be accomplished, along with a projected schedule, milestones, and deliverables. The major output is a Topside Antenna Systems Arrangement drawing. However, it is a long road leading to that output.

Providing antenna subsystems for modern warships presents many very difficult, and different, problems which do not arise in other technical disciplines.[9] This results, as illustrated in Figure 2, from the large number and variety of distinct services which have to be met, and the extremely restricted space where antennas can be placed. For example, think of the aircraft carrier, which, in addition to being a floating, mobile airport, is also a large radar station, a navigation and electronic countermeasure facility, a complex transmitter/receiver site, and a gunfire and missile launching platform. If just one of these functions, the radio communication services, were to be properly sited on shore, the area occupied by the necessary antennas would be hundreds of times the area actually available on the ship. On shore the transmitter and receiver facilities would be widely separated to avoid mutual interference. The shipboard situation, however, is such that mission requirements and priorities result in crowding of most antennas on, and around, the central superstructure. This problem is intensified to the point of near frustration on the aircraft carrier where, in order to keep the major portion of the ship, i.e., the flight deck, clear for aircraft operations, the inevitable conclusion is a congested and bewildering array of antennas about the ship's island. See Figure 3.

The clustering of so many antennas in so little space, plus the necessity for simultaneous emission and reception together with the undesirable, but unavoidable, electromagnetic coupling to, and reradiation from, a host of other shipboard metal objects, results in a most trying system integration problem for the ship antenna system engineer. Strenuous efforts must be made to reach a compromise with all competing topside subsystems so as to provide the least degradation in overall performance. The process is long, repetitive, and demanding.

Shipboard antennas generally fall into one of three groups:

. Omnidirectional antennas used mainly for communications, air navigation, and passive reception to satisfy the need of ships and aircraft to maneuver independently of each other and fixed radio stations.

. Directional antennas used for transmitting and receiving spatially concentrated energy in one direction at a time; e.g., radar, gunfire control, and satellite communication to obtain information about or from remote objects.

. Directional antennas used to determine bearing of incident radiation; e.g., direction finding navigation and Electronic Countermeasures (ECM).

To satisfy the requirements of these three groups, ship antenna design has evolved to the following major approaches:

. Broadband excitation of the masts and superstructure (e.g., wire rope "fan" type antennas).

. Probe excitation of ship structures (e.g. Omega VLF whip on mast).

. Tuned independent antennas (e.g. 35 foot whips with couplers)

. Directional, independent, antennas and arrays (e.g. SATCOM and radar)

After decades of specifying, and modifying, scores of individual antenna types have been produced to fill each need. Most, but not all, carry standard Navy nomenclature; e.g. AS-2537A, NT-66095, AT-924/SR and AS-2034/SPN-43. Whereas any one of these individual antennas might function very well when isolated, it is the problem of shipboard antenna systems integration to ensure that the resultant performance of each antenna is not hopelessly degraded when placed in the overall hostile electromagnetic environment of a surface ship.

There was a time, not too long ago, when the topside antenna design procedure consisted of an educated guess at the best layout for antennas in the superstructure, followed by attempts at experimental verification. This procedure was referred to, derogatorily, as "dartboarding." As ships became increasingly sophisticated, so too did their electronic sensor requirements. Ship commanders began to rely more and more heavily on electronic systems such as communications, radar, navigation, gunfire control, friend-or-foe identification, electronic countermeasures, and aircraft operations. Complex, intricate below-decks electronic equipment was found to be virtually useless unless matched with satisfactory antenna performance. The antenna system soon emerged as a key factor for reliable, quality performance. Former methods of antenna design and topside arrangements were no longer adequate. It was realized that shipboard antenna suits are not isolated, independent systems, but are, in fact, topside subsystems which must be tailored to each particular ship type to operate effectively within the constraints of very limited space and weight, high ambient rf fields, a highly corrosive atmospheric environment, and in competition with the many other users of the ship's topside. Dart-boarding disappeared - to be replaced by careful, scientific, planning. For new ships the general procedure is as follows:

. As outlined at some length earlier, from the mission requirements defined by CNO and set forth in the TLR (Top-Level Requirements) and ROC's (Required Operational Capabilities), an electronic equipment list with associated antennas is proposed.

. Preliminary studies of the hull (which itself is likely to be undergoing concurrent changes) are conducted to determine major compromises and trade-offs.

. The preliminary topside antenna arrangement is developed.

. An evaluation of the preliminary topside arrangement is performed by:

(a) NAVELEX 5103 for communications antennas using results of model analysis

(b) NAVSEC 6174D for performance potential assessment and predicted degradation

(c) NAVSEC 6174E for RADHAZ/EMC/HERO

(d) NAVSEC 6174F in coordination with all topside competitors.

. The final topside antenna arrangement is derived after several iterations of the preliminary configuration. The result represents a compromise solution to an extremely difficult problem.

Each of the above phases will be examined in depth:

Electronic Equipment List (Block 3 of Figure 1)

This list, normally prepared by the NAVSEA ship manager, identifies equipment required to meet each mission area of the ship as specified by CNO. Included in this list are the antennas and such ancillary equipment as couplers, tuners, preselector filter/amplifiers, etc. Development and production of these equipments fall within the combined responsibility of NAVSEA and NAVELEX.

Preliminary Studies (Blocks 4 and 5 of Figure 1)

Confronted with the first-cut outlines of a proposed new hull the antenna designer becomes concerned immediately with the interrelationships of major topside items: the height and shape of the superstructure, the placement of the deck weapon systems, location and form of the stacks, quantity and structure of masts, and available installation space for antennas. At this stage, by no means are any of the above fixed. Placement of large, high power HF antennas on deck will affect performance of the weapons, and vice versa. The quantity and weight of antennas proposed for mast mounting may determine the number of masts, and will certainly influence the shape and height of any mast. Height of the superstructure above the main deck may influence greatly the radiation characteristics and impedance of certain antennas. And so it goes, each item impacting the location and performance of the others. Only gross proposals can be suggested as solutions - with alternatives necessary.

An obvious first step in the antenna systems design process is to attempt to reduce the number of antennas required. Consider, for example, HF communications: it would be lovely for each antenna to be as efficient and broadband as possible - to handle a wide range of frequencies. The obstacle of size is immediately apparent. From a purely theoretical viewpoint, the ideal would be to have a half-wave vertical antenna (quarter-wave monopole, plus image, over perfect ground) for each frequency from 2-30 MHz, which, in a clear site, would provide omnidirectional coverage at low angles with low ground losses. Since, at 2 MHz this would require a 123 foot vertical antenna, such an ideal is not possible aboard ship. The Navy has compromised by selecting as its standard the 35-foot whip antenna, which becomes a half-wave antenna at 7 MHz. Though efficiency falls off rapidly below about 4 MHz, a height much above 35 feet becomes impractical. And, to allow operation of high power transmitters into a VSWR of 3:1 or less throughout the HF band, the vertical radiators are "fattened," by caging or trussing.

Continuing the quest for reduction of antennas, it next becomes evident that more than one transmitter (or receiver) should be connected to any one antenna. This naturally leads to multicouplers, not only to permit reduction in the number of antennas, but also lessening EM interaction through introduction of a degree of filtering and frequency isolation. The design goal is to have minimum channel spacing so as to allow a maximum number of communications channels. At the present time, through the use of modern shipboard HF multicouplers, minimum transmit-to-transmit separation is 5%, and transmit-to-receive separation is 8%.

It should be made clear at this point that a major input to the topside engineering design effort is provided by NAVELEX in the form of an external communications arrangement sketch, based in large part on model range studies.

Model Studies

Either at a naval laboratory or contractor facility, scaled models of the ship with its topside antenna complement are subjected to measurements to determine feasibility of the preliminary arrangement, or best alternative. These models, usually 1/48th scale, made of sheet brass, (Figures 4 and 5), include the various structural elements influencing antenna characteristics, and are tested on a model range, (Figure 6), simulating the sea. Based on the test measurements, changes in the model's topside structures are made quickly and easily, thereby greatly expediting the antenna placement design process. Model range tests have proved to be accurate and cost effective, and of invaluable aid throughout the life of a ship when future topside alterations may require a new set of model measurements.

To complement, and perhaps some day even supplant, brass modeling, the Navy is very actively engaged in computer math modeling. Using such numerical techniques as the Method-of-Moments (MOM) and Geometrical Theory of Diffraction (GTD) this work is being done principally by Naval Ocean Systems Center (NOSC), San Diego, in conjunction with their antenna model range. Individual antenna characteristics, and a few wire grid configurations coarsely simulating shipboard environments have already been math modeled with good success. Results have correlated very well

with brass model experimental measurements. As confidence in the math modeling procedures is gained, and the unexcelled speed and flexibility afforded by the computer in providing impedance, coupling, and radiation pattern results are fully utilized, it is anticipated that math modeling will become very extensively employed.

EMC and Performance Potential Analyses - (Block 6 of Figure 1)

Once a fairly good notion is obtained of the number and types of antennas required, the next step is to begin the placement of antennas on the superstructure, and to anticipate the impact that arrangement will have in terms of overall ship's predicted performance potential, electromagnetic interference (EMI), radiation hazards to personnel (RADHAZ) and to ordnance (HERO). In fact, it is this competition with other systems (and structures) that is most difficult to resolve in shipboard antenna design. A naive first approach that might come to mind is to locate all antennas as high as possible, in the clear, for all around transmission and reception. The masts and yardarms would seem the best choice. Unfortunately, as seen by Figure 7, there are problems with this choice: (a) communications engineers aren't alone in recognizing how nice this space would be - the radar engineers, navigational-aid engineers, and EW engineers have the same thoughts, (b) it is undesirable to have both transmit and receive antennas in the same frequency band collocated; one mode, either transmit or receive, has to be placed elsewhere. Normally, the transmit antennas are installed in the vicinity of the transmitter equipment room in order to minimize cable attenuation losses. And (c), some antennas, particularly transmit antennas in the low portion of the HF band, do not function well high off the water. Their radiation patterns begin to split, or "scallop," in the elevation plane. To compound the problem even further, the yardarms and masts are used also to support flag halyards (which become entangled in the antennas), commissioning pennants, navigation lights, and wind-speed indicators. Moreover, some communications antennas, especially in the HF range, are much too large and heavy for mast mounting.

As a result only antennas that absolutely require such locations can be mast mounted. For example, air-to-ground UHF communications antennas, TACAN, and DF antennas are installed high above the sea so as to get the maximum possible range and have an azimuthal radiation pattern which is as nearly circular as possible. For large, heavy antennas, other locations must be sought, and competition for real estate begins in earnest. On any ship there are areas which are immediately eliminated; e.g. helicopter take-off, landing, and vertical replenishment zones, gun arc-of-fire zones, missile launching zones, cargo and boat handling zones, and visual navigation zones. Additionally, antennas should not be installed on stacks or next to fuel handling areas and ordnance stowage. For the antenna system designer, installation space seems to evaporate.

Isolation between antennas is maximized to the greatest extent possible. Separation of communications receiving antennas from high power transmitting antennas is necessary to prevent overload of the

receivers and the generation of intermodulation products within the receivers. Isolation not adequately afforded by physical separation is compensated by frequency separation and filtering. It is also advisable, and in some cases imperative, that isolation be provided between antennas of different functions; e.g. communications and radar, or search radar-to-navigation radar. A typical case is the requirement for certain satellite communications antennas to be located well away from ship-to-ship UHF transmitting antennas. Of course, the very heart of the problem lies in the lack of flexibility in isolating antennas, due to the physical limitations of ship real estate. Shipboard EMC Improvement (SEMCIP) surveys have repeatedly revealed, and attempted to resolve, radar generated interference on aircraft carriers and heavy combatants resulting from so many radar antennas operating in so very small a volume.

The requirement for communicating in any direction requires that the pattern-distorting effects of the ship superstructure and rigging be taken into account and minimized. Large portions of the radio-frequency spectrum can be made useless by coupling into what appear to be isolated ship structures. It is an inherent characteristic of high-frequency antennas that they use the ship structure as part of the radiating element; the return path for RF energy is through the hull from the sea water "ground." The entire ship, from top of the mast to waterline, is a complex sheet of interacting RF current streams comprising the antenna systems; therefore, the ship structure has an inherent influence on individual antenna performance characteristics. Induction of electromagnetic energy from the desired radiator into nearby structures causes them to reradiate the signal and, in effect, become another part of the antenna system. These parasitic antennas distort the radiation pattern and affect the antenna impedance.

There are several other aspects of these induced currents which contribute to the shipboard problem. One of these concerns the running rigging, cargo hooks, and other metallic objects handled by ship's personnel. Voltages induced in these objects may be sufficient to cause startling RF burns to individuals grasping them. Another concern has to do with the generation of intermodulation products and broadband noise bursts in metallic junctions causing radio-frequency interference (RFI). This is due to rectification of non-linear metallic oxides which form at the junctions enabling the mixing of several signals to create entirely new products, or, if the contact is intermittent, to cause noise bursts across a wide frequency spectrum. Intermodulation and noise burst problems can be reduced by bonding of the junctions causing the RFI. However, since precise identification of these sources aboard ship is difficult, present practice is to bond all suspect junctions. This is an expensive proposition, compounded further by the fact that effective bonding cannot be accomplished on what might be the worst noise generator of all, the running rigging. A better solution than bonding involves the use of nonmetallic (dielectric) materials wherever possible. This has been applied successfully to lifelines, stanchions, ladders, and some cargo hooks; however, no material has been found which will replace the steel rope used in running rigging. It should be noted

that many of the effects just described are frequency dependent; i.e., they are more pronounced at certain frequencies, or frequency relationships, than at others. Avoidance of those frequencies tends to reduce RFI problems.

Taking all these electromagnetic energy interrelationships into account the search for suitable antenna installation locations is continued. Consultation with all other topside subsystem designers must be maintained on a routine basis through such means as Topside Design Information Exchange Team (TDIET) meetings. Weight and moment estimates of the deck mounted, and particularly the mast mounted, antennas and ancillary equipment must be provided to NAVSEC hull and mast designers. Optical blockages to microwave antennas are determined. Blast and thermal environment parameters must be derived, and the impact upon antenna systems analyzed. Where absolutely necessary, cam cut-outs must be incorporated into weapons systems. The total topside EM system performance potential is predicted, degradation allocated where required and recommendations to improve EMC provided. In short, performance compromises must be reached among all major topside systems - not only antennas, but weapons and deck operations as well.

Candidate Antenna Arrangements - (Block 7 of Figure 1)

As a result, in cooperation with all the various NAVSEC functional design codes - hull, machinery, arrangements, weapons, electrical, etc. - candidate topside configurations are proposed. A typical design approach to any problem is to tabulate existing data related to the projects in a series of alternative solutions.(10) The alternatives fulfill each of the requirements to the greatest extent possible; however, it is recognized that no single solution is capable of meeting all requirements. The trade-off studies determine those alternatives most nearly meeting requirements, with the risks inherent in selection of each alternative. Recommendations are made to the Ship Design Manager, proposing that alternative most nearly meeting requirements, with documented rationale for the selection, including the identification of any risks and deficiencies of the resultant system. The Ship Design Manager then has the prerogative of accepting the proposed alternative or reallocating space, weight and power to achieve the desired performance, taking into consideration the impacts upon the remaining ship subsystem and overall cost. Whichever decision he settles upon, his selection of a particular topside configuration then becomes the baseline arrangement drawing.

The baseline topside antenna design is refined over and over, with many of the changes necessitated by policy decisions involving such diverse factors as ship cost, size, and manning. The several system commands either participate in the iterations through both formal and informal design reviews, or are kept advised of the impacts on their subsystems.

Revised and updated topside arrangement drawings are prepared and circulated to all cognizant hull, machinery, electrical, arrangements, and weapons codes of NAVSEC, for general information and impact assessments, to NAVAIR for aircraft operations clearance, and to NAVELEX for review and comments. The final drawing resulting from the total ship design is included in the technical documentation to be used for ship acquisition.

Design Output - Topside Antenna Drawing - (Block 9 of Figure 1)

With the antenna arrangement contract drawing completed, signed, and distributed, configuration control is maintained thereafter by NAVSEC's Topside Antenna System Integration code. Revisions to this drawing during the shipbuilding process, and changes brought about by topside alterations and upgrading of electronic systems during the lifetime of the ship are reflected on this original contract antenna drawing, which is then issued, as revised, to all concerned.

Post-Design Phase

Has the shipboard antenna system design and integration process finally reached completion? Unfortunately, the answer is no. During both the shipbuilding and life cycle periods, changes are made, ranging from simple addition of platforms and structural reinforcements to major changes in ship equipment complement. Such changes will more often than not affect antenna characteristics, usually adversely.

Examples of topside changes which can seriously degrade antenna performance include addition of deck houses; extensions to bridge wings; modifications of mast and yardarm configurations; additions, deletions, or relocations of antennas; and changes in radar and weapons systems. Since each antenna has been previously custom fitted to its specific environment, piecemeal alterations may have a dramatic effect upon antenna performance.

Conclusions

Despite a multiplicity of missions requiring support of electronic subsystems, all of which require electromagnetic sensors, the ship can offer only a very small volume for antenna installations. Compressed so tightly on the mast and about the open decks, interaction of the many antennas, both with themselves and with the many other nearby electronic and metal objects, is intense and unrelieved. Integration of the various antennas into this hostile environment is difficult, requiring a long, patient effort of continuous coordination with the several ship systems planners in order to achieve a compromise solution offering adequate overall performance with minimum degradation.

System integration engineers are struggling day-by-day to resolve problems such as:

. Where to best place antennas to eliminate, if at all possible or to at least minimize, interference between the CCA (carrier-controlled approach), air, and surface search radar functions on aircraft carriers.

. How to integrate such new weapons systems as NSSMS, CIWS, and ASMD, with their associated sensors, into the topside without seriously upsetting the existing precarious balance of performance.

. Where to find space for very large, very heavy, eight foot diameter SATCOM dish antennas and, at the same time, keep at a bare minimum the potential RADHAZ and RFI associated with these antennas.

. Where to find a vacant spot for newly imposed requirements such as SSES and LAMPS when the highest, clearest mast locations are already occupied by TACAN, DF, UHF communications, and task lights.

There are neither any completely satisfactory, nor satisfying, solutions. Nevertheless, using the best of available resources and expertise, the job must be done. An understanding by the Navy community of the complexities involved - and a more cooperative spirit by all - will certainly do much to facilitate the attainment of an adequate design.

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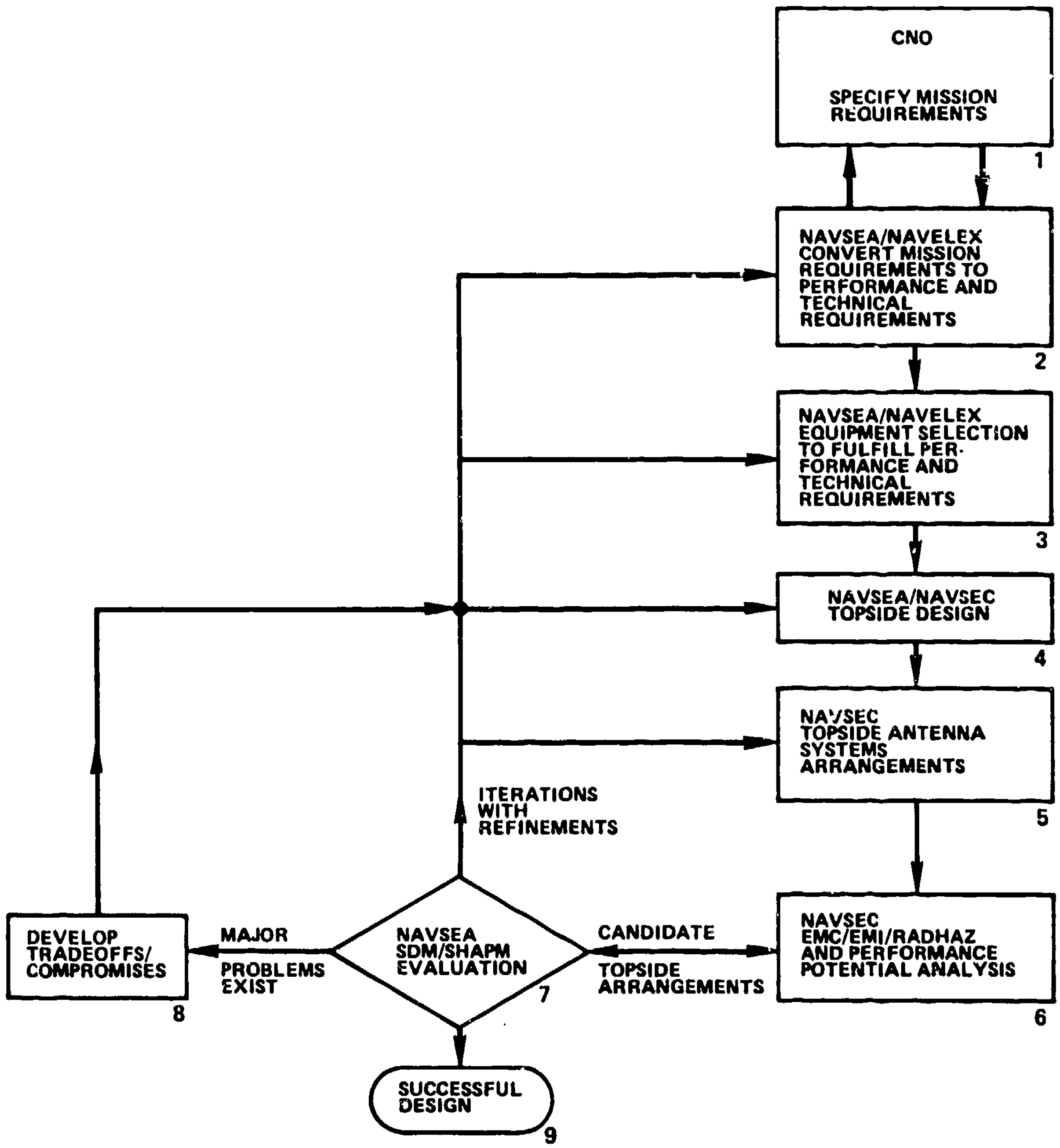

FIG. 1 FUNCTIONAL BLOCK DIAGRAM OF THE ELECTOMAGNETIC SYSTEMS PORTION OF THE SHIP DESIGN PROCESS

RADIO
ANT RCVR PATCH PANEL
(FACILITIES CONTROL RM)
1 1-1 AT-924/SRA-17C (FR105 (P))
2 1-2 AT-924/SRA-17C (FWD (P) MAST LEG)
3 1-3 AT-924/SRA-17C (FR101 (P))
*4 1-4 AT-924/SRA-17A (FR98 (P))
5 1-5 AT-924/SRA-17C (FWD (S) MAST LEG)
*6 1-6 66047 TILTING WHIP (FR6 (S))
7 1-7A 45' DUAL TLG WHIPS (2-6MHZ)(FRC (P))
8 1-7B 45' DUAL TLG WHIPS (2-6MHZ)(FRC (S))
9 1-8A 35' DUAL TLG WHIPS (4-12MHZ)(FR24 (P))
10 1-8B 35' DUAL TLG WHIPS (4-12MHZ)(FR24 (S))
11 1-9A 17' DUAL TLG WHIPS (10-30MHZ)(FR37 (P))
12 1-9B 17' DUAL TLG WHIPS (10-30MHZ)(FR37 (S))

AN/SRR-1 (FAC CONT RM)
*13 1-10 AS-2815/SRR-1 (FR109½ (P))
14 1-11 AS-2815/SRR-1 (FR88 (S))
*15 1-12 AS-2815/SRR-1 (FR125½ (P))
*16 1-13 AS-2815/SRR-1 (FR124 (S))

AN/URC-16 (RADIO XMTR RM #1)
17 2-1 TWIN FAN WR (2-6MHZ) FR93-112 (P/S)
18 2-2 BROADBAND WHIP (4-12MHZ) FR124 (C)
19 2-3 BROADBAND WHIP (9-27MHZ) FR117 (P)

ANT XMTR PANEL (RADIO XMTR RM #1)
20 2-4 66047 WHIP (FR93 (S))
21 2-5 66047 TILTING WHIP (FR160 (S))
22 2-6 66047 WHIP (FR111 (P))

RADIO XMTR RM #1
*23 2-7 AT-924/SRC-17C (FR230 (S))(WRR-3)
*24 3-1 FAN WR (FR162-185 (S))(WRT-1 #2-1)

RADIO XMTR RM #II
*25 3-2 FAN WR (FR162-165 (P))(WRT-1 #3-1)
26 3-3 66047 TLG WHIP (FR167 (P))(WRC-1 #1)

ANT XMTR PATCH PANEL (RADIO XMTR RM #II)
27 3-4 66047 TILTING WHIP (FR223 (S))
*28 3-5 66047 TILTING WHIP (FR186 (S))
29 3-6 66047 TILTING WHIP (FR212 (S))
30 3-7 66047 TILTING WHIP (FR197 (P))
31 3-8 66047 TLG WHIP (FR140 (P))(WRC-1 #2)
32 3-9 AT-924/SRC-17C (FR234 (P)) AN/WRR-3

AN/SRA-33 #1 (RADIO RM)
33 4-1A AS-1496/U PHASOR 90 (FR89 (S))
34 4-1B AS-1497/U PHASOR 90 (FR118-3/4 (S))
35 4-1C AS-1496/U PHASOR 90 (FR125 (S))
36 4-1D AS-1497/U PHASOR 90 (FR101 (P))

AN/SRA-33 #2 (RADIO RM)
37 4-2A AS-1497/U PHASOR 90 (FR89 (℄)
38 4-2B AS-1496/U PHASOR 90 (FR119-3/4 (S))
39 4-2C AS-1497/U PHASOR 90 (FR125 (℄))
40 4-2D AS-1496/U PHASOR 90 (FR103 (P))

AN/SRA-33 #3 (RADIO RM)
41 4-3A AS-1496/U PHASOR 90 (FR89 (P))
42 4-3B AS-1496/U PHASOR 90 (FR118 (S))
43 4-3C AS-1496/U PHASOR 90 (FR125 (P))
44 4-3D AS-1497/U PHASOR 90 (FR118 (P))

UHF RADIO RM
45 4-4 AS-1018/URC(FR103(P))ANT YDARM(SRC-21 #21)
46 4-5 AS-390/SRC (FR103(P))ANT YDARM (SRC-21 #22)
47 4-6 AS-1018/URC(FR103(S))ANT YDARM(SRC-21 #23)
48 4-7 AS-390/SRC (FR103(S))ANT YDARM(SRC-21 #24)
49 4-8 66095 (FR103(P)) SIG YDARM (SRC-29)
50 4-9 66095 (FR103(S)) SIG YDARM
AN/URT-7 & AN/URR-27
51 4-10 AS-390/SRC(FR103(P))SIG YDARM (SRC-20 #17)
52 4-11 AS-1018/URC (FR103 (S)) URC-4A PLAT
AN/SRA-33 #4
53 4-12 AS-1018/URC (FR103 (P)) URC-4A PLAT
AN/SRA-33 #3
(RADIO RM #2)
54 5-1 AS-1018/URC(FR106 (℄)) AN/SPS-10 PLAT
CU-1559/U
55 5-2 AS-390/SRC (FR103 (S)) SIG YDARM (CU-1559/U)

ANT PATCH PANEL (METEOROLOGICAL)
56 7-1 AT-924/SRA-17C (FR97 (P))
57 7-2 66047 WHIP (FR93 (P))
58 7-3 AT-924/SRA-17C (FR100 (℄))

AN/ARC-51 (CATCC)
*59 8-1 AS-390/SRC (FR17 (S))
AN/ARC-51
*60 8-2 AS-390/SRC (FR118 (P))
AN/ARC-51 (LSO)
61 8-3 AS-390/SRC (FR112 (P)) (PRI-FLY)
AN/URC-22 (FLIGHT DK CONTROL STATION)
*62 8-4 AT-1180/URC-22 (FR119 (P))
*63 8-5 AT-1086/SRC-22 (FR124 (P))

ANT RCVR PATCH PANEL (SUPRAD)
*64 13-2 66047 TILTING TRUSSED WHIP (FR15 (S))
65 13-3 66047 TILTING TRUSSED WHIP (FR8 (P))
*66 13-5 AS-1049/SLR TILTING DISCAGE (FR17 (P))
*67 13-1 AT-924/SRA-17C WHIP (FR 2 (P))
*68 13-4 DISCONE/DISCAGE ANT (FR 1 (S))

BEACON (LOOKOUT STATION #1/#2)
*69 1A T-438/UAT-4 (P) SIGNAL YDARM
*70 1B T-438/UAT-4 (S) SIGNAL YDARM
71 3 OA-7203A/URN-20 (℄ FR103,
DUAL TACAN (ECM RM #3)
CCA
72 OE-138/SPN-43A FR106(P))(SPN-43 RCR RM)
73 (?) AS-1144/SPN-10 (℄ FR124-126)
(RADAR RM #7)
*74 RT-305/SPN-12(P FR123) (RADAR RM #3)

IFF (RADAR RM #2)
*75 40-1 AS-177/UPX (FR100 (P)) (APX-72)
*76 40-2 AT-177/UPX (FR100 (S)) (TEST #1)
*77 40-3 AS-177/UPX (FR103 (S)) (TEST #2)
*78 40-4 AS-177/UPX (FR103 (S)) (SPS-10)
*79 40-5 AS-177/UPX (FR103 (P)) (SPS-30)
80 40-6 AS-177/UPX (FR100 (S)) (SPS-37A)
81 40-7 AS-177/UPX (FR106 (S)) (SPS-43A)
82 AS-1065/UPX(W/AS-791/UPA-43 PEDESTAL)
FR96 (℄) (SLAVED AN/SPS-30)
83 AT-3527/UPA-27 (FR111 (S))
(INTEGRAL AN/SPS-37A)
84 AS-2188/U (FR106 (P))(W/OE-138/SPN-43A ANT)

ECM (CIC-ECM AREA)
*85 23 AS-2209/SLR-12A(ECM PLAT (AFT))
(RADAR RM #2)
86 24 AS-571/SLR (P)
87 25 AS-616/SLR (S)
88 26 AS-899B/SLR (P)
89 27A NT-66132 (P)
90 27B NT-66132 (S)
*91 28A NT-66131 (P)
92 28B NT-66131 (S)
*93 6A AN/ULQ-6B ANTENNA ARRAY(FR85 (P))

(ECM RM #2)
AS-1750/SL FIXED ANT (RCVR) UPPER
AS-1751/SLA-12 TRAINABLE
AS-1750/SL FIXED ANT (XMTR) LOWER
94 6B AN/ULQ-6B ANTENNA ARRAY (FR104 (S))

(ECM RM #3)
AS-1750/SL FIXED ANT (RCVR) UPPER
AS-1751/SLA-12 TRAINABLE
AS-1750/SL FIXED ANT (XMTR) LOWER
95 AS-1167/SPS-30 (℄ FR98,
(RADAR RM #4)
96 AN/SPS-37A (℄ FR 114)
(RADAR RM #6)
97 AS-936/SPS-10C (℄ FR101)
(RADAR RM #2A)
98 PATHFINDER (NAV BRIDGE) (FR90 (℄))
SHORT RANGE NAVIGATIONAL
99 4A AS-514A URD-4 (FR101 (℄))
AN/URD-4A RCVR (UHF RDO RM)
100 10 AN/URN-9 ANT GROUP (FR106 (℄))
(CHART HOUSE)
101 14-1 AS-2271/SRN-14 (FR106 (℄)) OMEGA
(CHART HOUSE)
*102 32 AN/SRA-40 LORAN WHIP (FR100 (S))
AN/UPN-12C (CHART HOUSE)

RADIO NCE
*103 2A AT-775/SMQ-1 (03 LVL FR232 (P))
AN/SMQ-1A (BALLOON INFLATION RM)
*104 2B AT-775/SMQ-1 (03 LVL FR226 (S))
AN/SMQ-1A (BALLOON INFLATION RM)
105 AN/SMQ-6 ANT (FR90 (P)) METRL FF
106 TACSAT COMM ANT #1 (FR89 (S))
(FAC CONT RM)
*107 TACSAT COMM ANT #2 (FR120 (P))
(FAC CONT RM)
*108 AS-1915/SPN-10 (FR204½ (℄)) RCR RM #8
109 AS-390/SRC (FR89 (℄))
(AN/SRC-21 FLAG BRIDGE)
*110 AS-390/SRC (FR89 (℄))
(AN/SRC-21 NAV. BRIDGE)

(AN/SPN-41 SHPT RM)
111 OE-32/SPN-41 AZ ANT(20.5' BELOW FLT DK)
(FR229 ℄ OF CANTED DK)
112 AS-2581/UPN AZ MON ANT (FR234 AFT)
113 OE-33/SPN-41 EL ANT (FLT DK FR108 (S))
*114 AS-2581/UPN AZ MON ANT
FLT DK WALK WAY (FR228 (S))

FIG. 2 TYPICAL ANTENNA REQUIREMENTS ON A LARGE WARSHIP

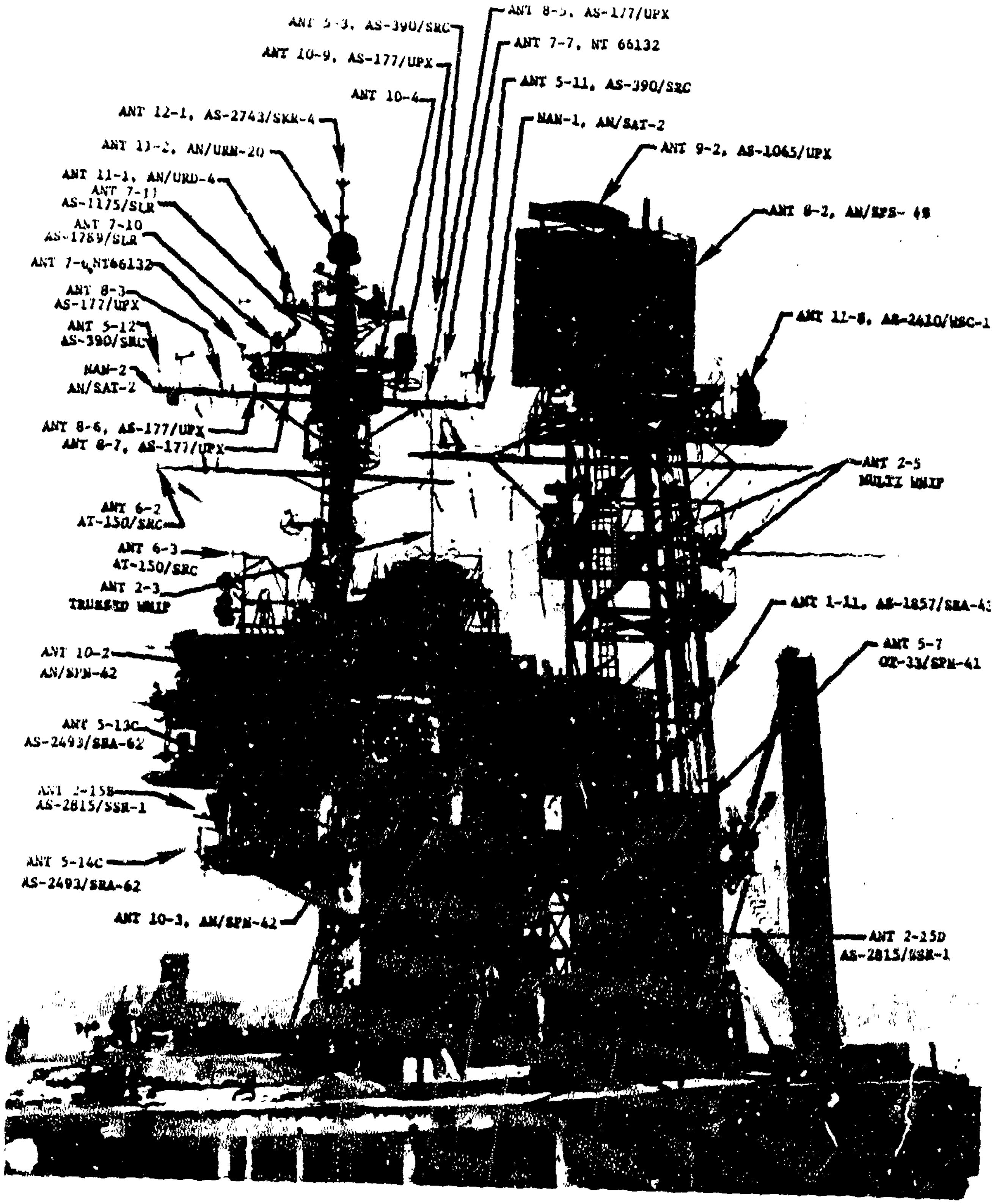

FIG. 3 ANTENNAS ON CARRIER ISLAND

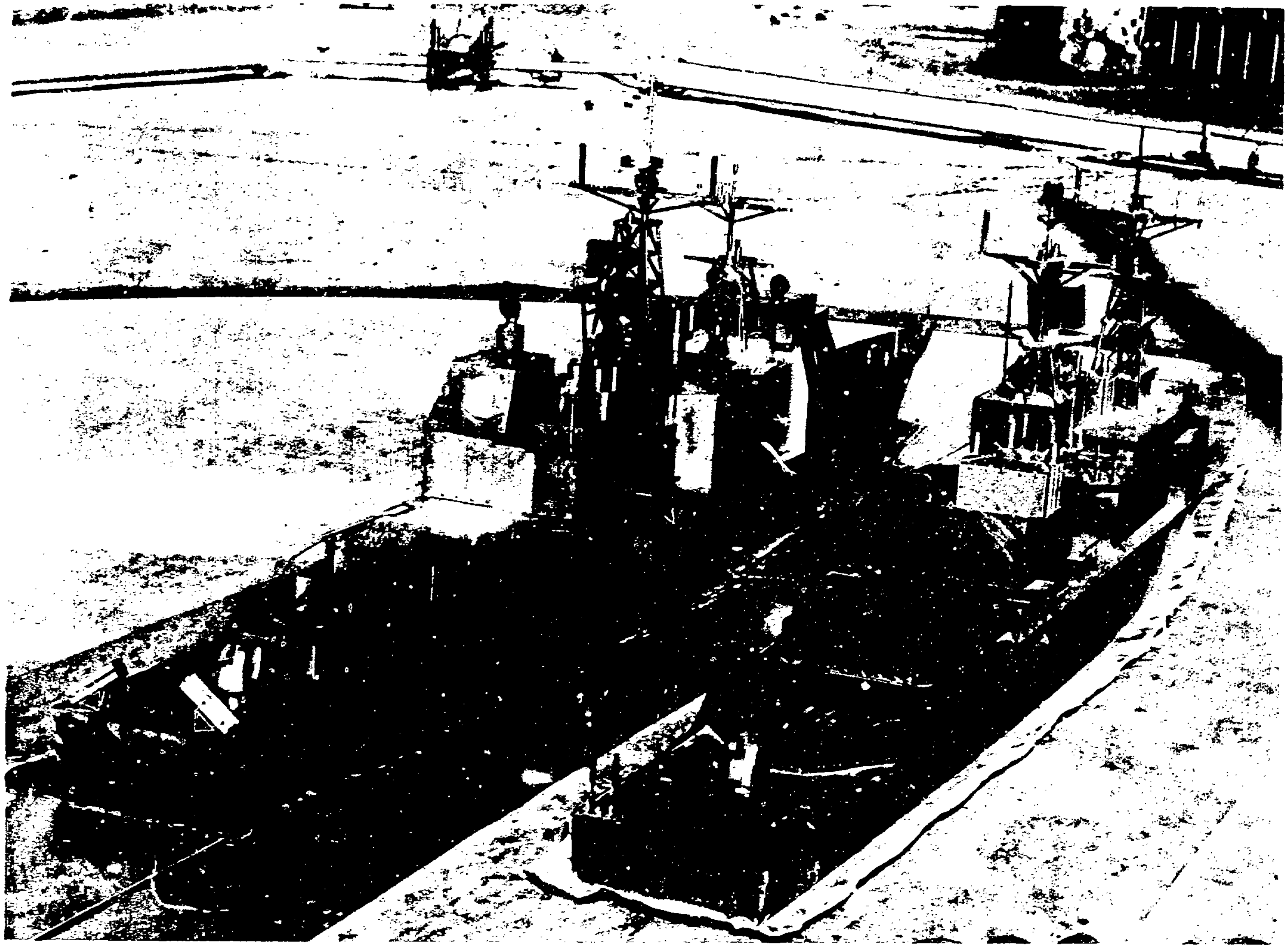

FIG. 4 SCALED BRASS MODELS

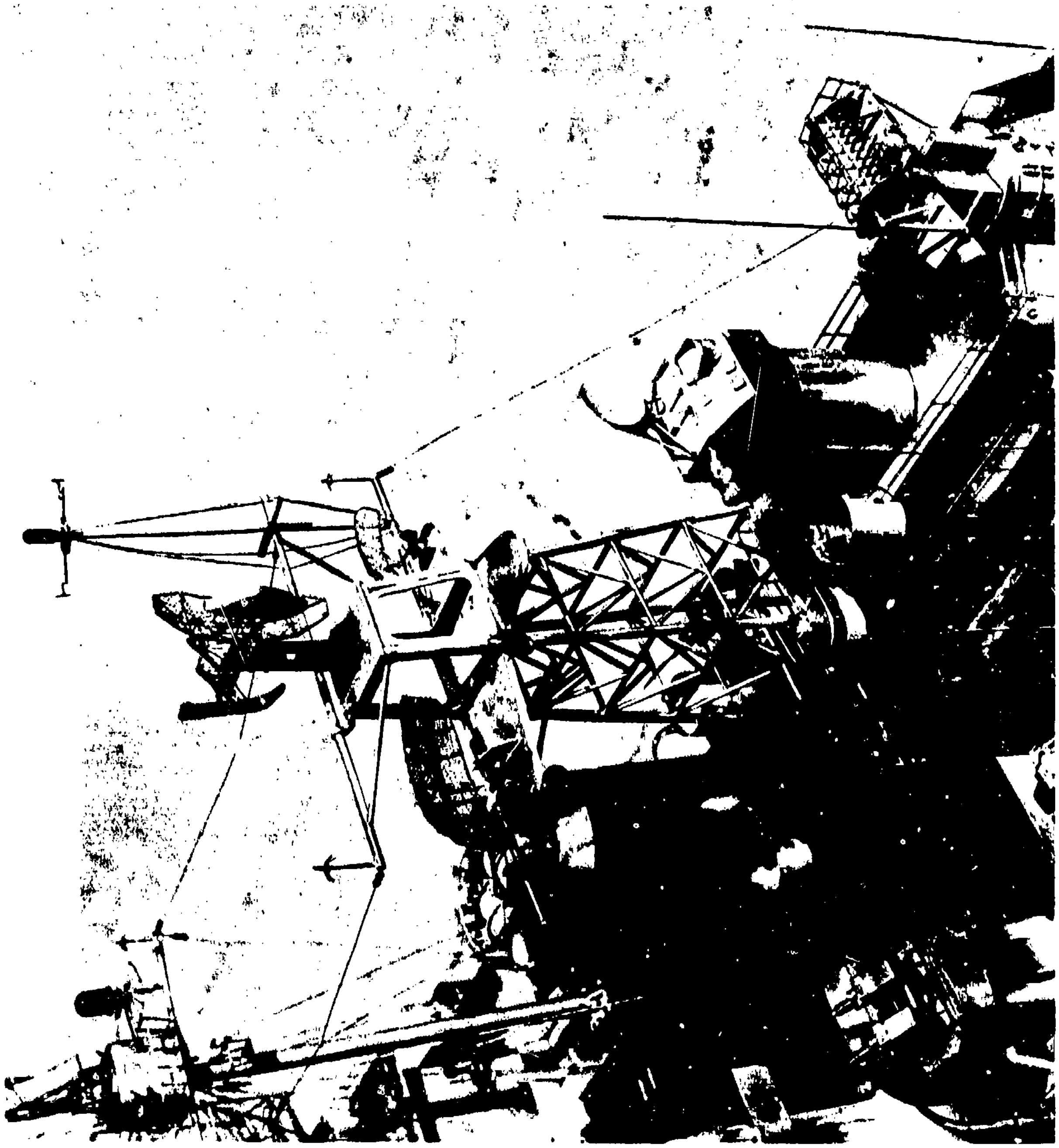

FIG. 5 SCALED BRASS MODEL - MAST AREAS

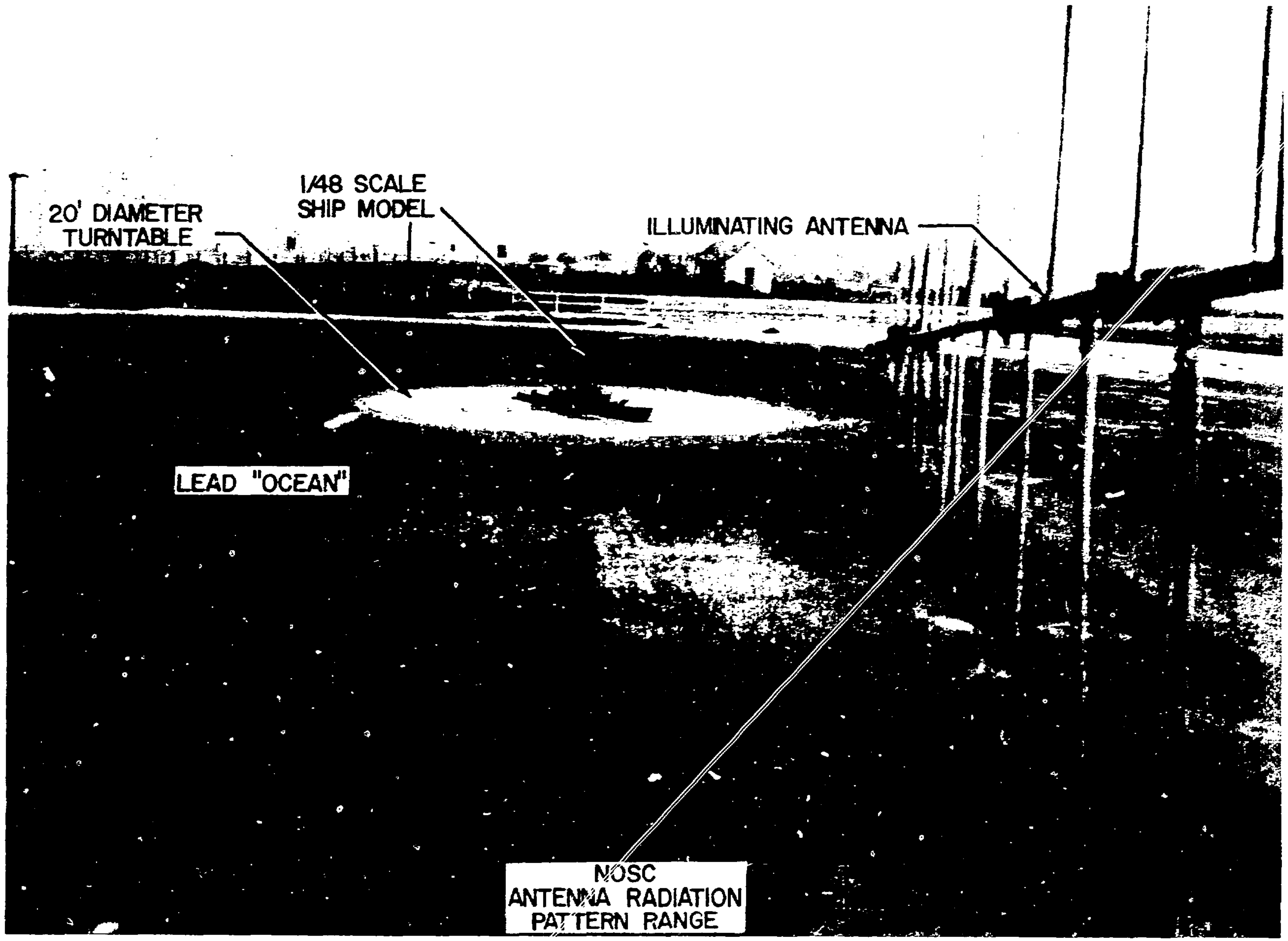

FIG. 6 SCALED MODEL ON TEST RANGE